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A COMPARISON OF EQUATORIAL ELECTRON DENSITIES MEASURED BY WHISTLERS AND BY A SATELLITE RADIO TECHNIQUE

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Abstract. For the first time, data on magnetospheric equatorial electron density from multiple whistler paths have been compared with in situ satellite measurements of electron density along near-equatorial orbits. The whistler data were recorded at Siple, Antarctica (L ~ 4.2) on June 28 and July 10, 1978, and at Palmer, Antarctica (L ~ 2.3) on April 10, 1978. The satellite data were obtained by the University of Iowa Plasma Wave Experiment sweep frequency receiver (SFR) on ISEE-1 during passes that remained within ~±15° of the observing whistler station's longitude. The compared data are mostly in the range 3 < L < 5.2 and represent the nightside magnetosphere under calm to moderately disturbed magnetic conditions. The results show good agreement on density levels, and support the assumption that the electron density distribution along the high altitude part of field lines in the outer plasmasphere can be described by a diffusive-equilibrium model. The data further suggest that the densities within the observed whistler ducts were within less than 30% of the mean or interduct level, and that over the L ranges of the comparisons, there were no significant east-west density gradients within about ±15° of the whistler station's longitude.

INTRODUCTION

The whistler method of determining electron density near the earth's magnetic equator is in many respects complementary to in situ measurements. Whistlers can provide excellent time resolution and extended time coverage at particular locations. Data are obtained simultaneously from multiple points in L space. In contrast, satellites can provide local measurements and excellent spatial resolution along their orbits.

Several comparisons of whistler and satellite data on plasmapause location have been made, and have generally shown good agreement [e.g., Carpenter et al., 1969; Maynard and Grebowsky, 1977]. However, comparisons of data on electron concentration have been few in number. There is better than order-of-magnitude agreement between typical plasmapause densities near L = 3.5 reported from whistlers and plasmapause profiles reported from spacecraft observations by Taylor et al. [1970] and Chappell [1972]. However, only one rendezvous situation has been reported [Carpenter and Chappell, 1973]. There was good agreement, but data were available from a single whistler path only.

The operation of ISEE-1 in rendezvous with whistler stations at Siple, Antarctica (L ~ 4.2) and at Palmer, Antarctica (L ~ 2.3) has afforded new opportunities to compare results from whistlers for the range 3 < L < 5.2 with the sweep frequency receiver (SFR) data from the University of Iowa Plasma Wave Experiments. The purpose of this note is to report on an initial series of comparisons involving 1978 data.

The whistler method

Measurements of a particular whistler component provide two parameters: path equatorial electron cyclotron frequency, from which the equatorial radius of the whistler path may be inferred, and equatorial number density [e.g., Smith, 1961a; Park, 1972]. A lightning flash may excite many ducts extending to many different earth radii. As a result, a corresponding number of data points on an equatorial profile of electron density may be estimated.

The whistler method provides an integral measure of electron density along a field-aligned path; that is, a field-aligned model of the density distribution is assumed and a scale factor of the density model is determined from the measurements. A diffusive-equilibrium model of the density distribution [e.g., Angerami and Thomas, 1963] is commonly used for analysis within the plasmasphere.

Whistler propagation is assumed to be in field-aligned ducts of enhanced ionization [e.g., Smith, 1961b]; hence the density measurements from whistlers are representative of conditions within the duct. The duct enhancement factors are predicted by theory to be relatively modest, of order 20% at middle latitudes [Smith, 1961b].

The duct L values or equatorial radii can be determined relatively accurately from ground-based measurements. The longitude is known less precisely; the paths may be distributed in longitude over the station's observing 'window' of ~±15° [e.g., Carpenter, 1966; Smith et al., 1981]. In the present case of relatively strong events, the paths can probably be assumed to lie within ~±10° of the observing meridian, but cannot be located more precisely than this unless direction-finding (DF) techniques are available.

SFR method on ISEE-1

The data from the sweep frequency receiver on ISEE-1 allows very accurate sheath-independent measurements to be made of the plasma density through almost the entire spacecraft orbit. The sweep frequency receiver has 128 channels approximately logarithmically spaced from 100 Hz to 400 kHz with a $\Delta f/f$ of about 6.5% [Gurnett et al., 1978, 1979]. A complete frequency scan is made every 32 secs. Mosier et al. [1973] have shown

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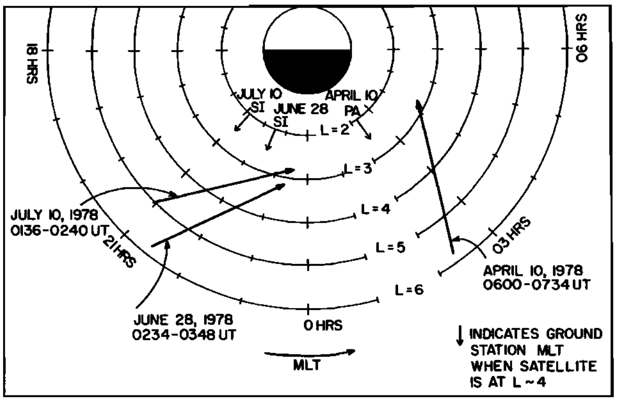

Fig. 1. Equatorial projections of the three ISEE orbits along which data were taken in rendezvous with the Siple and Palmer, Antarctica, ground whistler stations.

that within the plasmasphere intense noise bands occur between the upper hybrid resonance (UHR) frequency ($f_{UHR} = \sqrt{f_p^2 + f_g^2}$ where f_p = electron plasma frequency and f_g = electron cyclotron frequency) and f_p. Moderately intense UHR emissions are observed on almost every ISEE-1 pass through the plasmasphere; hence it is possible to determine the electron number density in situ. For the region of the plasmasphere we are investigating $f_p >> f_g$ and the difference between f_p and f_{UHR} is less than 2%. Thus the error in equating f_p to f_{UHR} is considerably less than the frequency spacing fraction of the SFR channels. Once f_p is measured, the number density, n_e, is determined from the equation $f_p = 8.98 \times \sqrt{n_e(cm^{-3})}$ kHz.

DESCRIPTIONS OF THE DATA

The ground data were acquired at the Antarctic stations Siple (L ~ 4.2) and Palmer (L ~ 2.3). The field line connecting Siple and the conjugate region crosses the magnetic equator at approximately 75°W, while the corresponding field line from Palmer crosses at about 66°W. The data employed in the present study were acquired in rendezvous situations when well-defined whistlers were recorded and when the ISEE spacecraft was moving in the middle magnetosphere within ~20° of the magnetic equator. Three cases meeting these criteria have been acquired to date and are described here.

Three rendezvous, on April 10, June 28, and July 10, 1978, are illustrated in Figure 1 in coordinates of L and magnetic local time. The segments of orbits shown cover the time periods for which the SFR data are plotted in later figures. The magnetic local time of the ground station is shown by a radial arrow for the time when the satellite reached L ~ 4 (Siple for June 28 and July 10; Palmer for April 10). This description seems sufficient, since the whistlers observed were recorded at various times during the indicated satellite passages, and with an uncertainty in longitude of order ±10° (as noted in an earlier paragraph). From Figure 1 we estimate that the longitude separations of whistler ducts and satellite were generally less than 20° over the range L ~ 3.5-5.

DATA COMPARISONS

Figures 2, 3 and 4 show the observed density profiles. Squares show the whistler measurements, while filled circles represent the ISEE-1 SFR data. The whistler data represent equatorial density, while the SFR data represent the in situ number density at the satellite position which is indicated below the figures. The expected difference between the electron density at the satellite and the equator is of order 5% for the cases reported here, an amount that is small compared to uncertainties in the compared measurements.

Occasionally more than one SFR measurement is shown for a given L value. This occurs when the upper hybrid resonance band appears in more than one SFR frequency channel. This could also be due to additional emissions around the upper hybrid resonance frequency or it could be due to the number density near the spacecraft fluctuating more rapidly than the 32-sec sweep time of the sweep frequency receiver. However, these uncertainties do not greatly affect the trend of the data. K_p information is shown at the upper right.

Figure 2 shows the case of July 10, 1978, for which the whistler results were the most detailed. The ±30% error bars on the whistler data represent uncertainty in the diffusive equilibrium model of the plasma density used in the calculations. For all the cases of this paper, a standard DE-1 model was used [Park, 1972] with $T_e = T_i$ = 1600°K and 90% O^+, 8% H^+, and 2% He^+ at the 1000-km reference level. If these parameters are varied relatively widely [Angerami, 1966], the calculated n_e values vary over an approximately ±30% range.

The whistler results were calculated using a dipole magnetic field model. Corrections to the calculated values based on more refined geomagnetic models would involve essentially no change in the mean profile levels, and only a slight, order of ~0.1 R_E, inward adjustment in the L values of the individual data points [Seely, 1977].

Figures 3 and 4 show the data for April 10 and June 28, 1978, respectively. On April 10 (Figure 3), there was evidence of a plasmapause effect near L = 5.5. This case and that of Figure 2 were preceded by relatively quiet conditions; in both

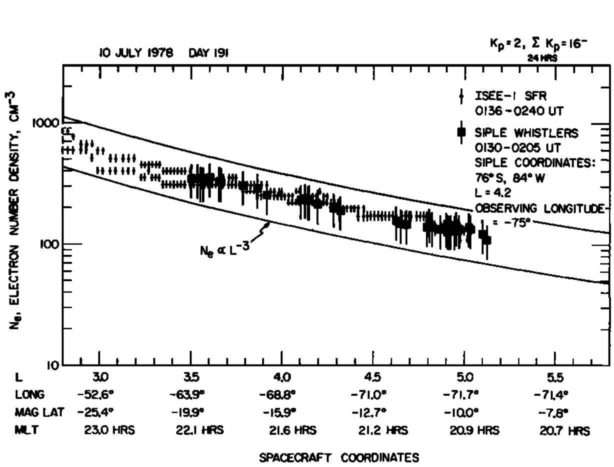

Fig. 2. Comparison of electron-density profiles in the magnetosphere determined from sweep frequency receiver data on the ISEE-1 spacecraft and from whistlers recorded at Siple Station, Antarctica, on July 10, 1978.

cases the profiles fell off roughly as L^{-3} within the plasmasphere. Profile values near L = 4 were higher on April 10 than on July 10 by a factor of 1.5, possibly as a result of a longer period of preceding quiet, and hence recovery from earlier depletions.

The June 28 case of Figure 4 represents a period of somewhat greater disturbance (K_p = 3-, ΣK_p = 22+ in the preceding 24 hours). Near L = 3 the levels were characteristic of the plasmasphere. Between L ~ 3.3 and L ~ 4.5, the profile fell off irregularly as ~L^{-9}. This falloff was much more gradual than that of a recently established plasmapause [e.g., Angerami and Carpenter, 1966; Chappell, 1972]; it may have resulted in part from repeated interruptions of recovery by moderate substorms, a phenomenon of the type reported by Corcuff et al. [1972]. Beyond L = 4.5, the profile changed relatively gradually, as ~L^{-3}, and the density levels were a factor of ~4 below those recorded (out to L ~ 5.2) on April 10 and July 10. This is further evidence of a recovery state; before recovery, plasmatrough density levels often reach a factor of 10-100 below typical plasmasphere levels of the period [e.g., Angerami and Carpenter, 1966; Chappell, 1972]. The SFR data shown in Figure 4 suggest the presence of several duct-like features (both troughs and crests) with a spatial size of 0.1 to 0.2 R_E.

INTERPRETATIONS

The DE model of the field line distribution

If we assume that the SFR data are correct within experimental error, then the good agreement of the three data sets suggests that within the plasmasphere and under the conditions illustrated, the DE model as applied was an appropriate choice for calculating equatorial densities. There is no basis in the data for inferring additional parameters of the model, but there is support for the existence of a DE-like (or relatively slowly-varying, as ~R^{-1}) distribution of plasma over the outer part of the field line paths. (Use of a model varying along the field lines as R^{-4} leads to density levels calculated from whistlers that are lower than the SFR levels by a factor of 2 to 3.) This result extends previous empirical studies in which the upper intensity cutoff frequencies of ducted whistlers observed on the ground [Carpenter, 1968] and group delays of whistlers observed on satellites [Angerami, 1970] were interpreted as supporting the existence in the plasmasphere of a DE-like field line distribution.

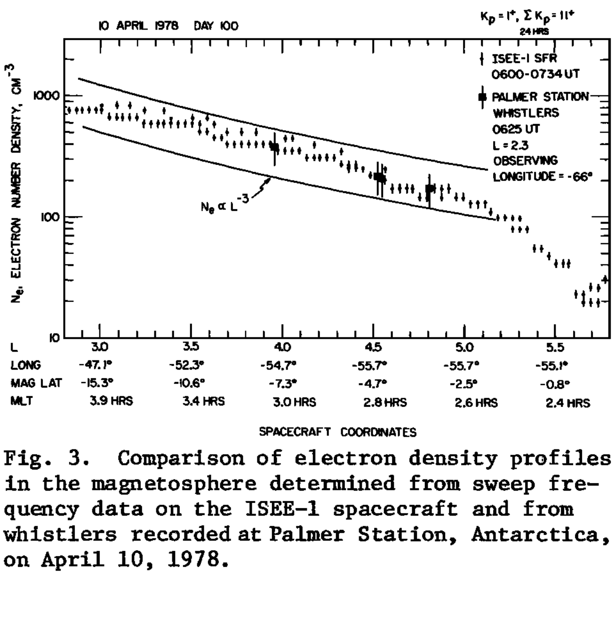

Fig. 3. Comparison of electron density profiles in the magnetosphere determined from sweep frequency data on the ISEE-1 spacecraft and from whistlers recorded at Palmer Station, Antarctica, on April 10, 1978.

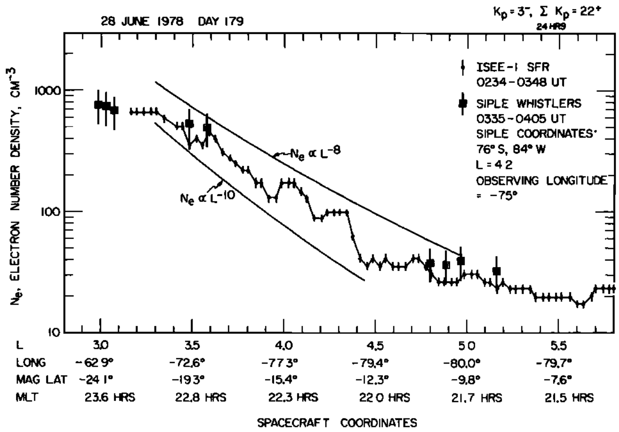

Fig. 4. Comparison of electron density profiles in the magnetosphere determined from sweep frequency receiver data on the ISEE-1 spacecraft and from whistlers recorded at Siple Station, Antarctica, on June 28, 1978.

Ducts

When longitudinal variations are ignored, the compared data sets suggest that within whistler ducts the densities were within ±30% of the mean level shown by the SFR. This suggests that enhancements within the ducts were not more than about 30% in these cases, and were thus in a range envisioned by earlier propagation theory [Smith, 1961b]. These findings are consistent with the earlier work of Angerami [1970], who concluded from a combination of ground and Ogo-3 satellite whistler data that the density enhancements in plasmaspheric whistler ducts near L = 4 generally lie between 6% and 22%, and rarely exceed 33%.

East-west density gradients

The three cases involve longitudinal separations of whistler ducts and satellite up to an estimated 20% within L = 3.5-5.0. The nominal longitudinal viewing window of a sensitive whistler receiver during periods of suitable lightning source activity is ~±15°. During moderately disturbed periods it is not uncommon to detect longitudinal structure within the plasmasphere [Park and Carpenter, 1970]. The largest such variations within the plasmasphere have been found to involve a factor of ~2 in level. The signature of longitudinal structure is relatively clear in spectrographic records of whistlers. None was observed in the present case studies, although the number of whistler components in two of them was relatively small. When whistlers exhibit many components, as on July 10 (Figure 2), and also reveal a relatively smooth n_{eq}-vs-L distribution, it is inferred that there are no significant east-west density gradients in the viewing range of the receiver. This seems to be borne out by the present observations; on all three days ISEE recorded profiles consistent with the whistler measurements, in spite of separations of up to ~20° in longitude.

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